

P22308

WRITE COMPENSATION CIRCUIT AND SIGNAL INTERPOLATION CIRCUIT  
OF RECORDING DEVICE

## BACKGROUND OF THE INVENTION

## 1. FIELD OF THE INVENTION:

5       The present invention relates to a write  
compensation circuit and a signal interpolation circuit.  
The signal interpolation circuit of this invention receives  
a pair of input signals having different phases and outputs  
a pair of output signals each having a phase similar to that  
10       of the corresponding input signal and another output signal  
having a phase intermediate between the pair of output  
signals.

## 2. DESCRIPTION OF THE RELATED ART:

15       Upon reproduction of data recorded in a recording  
device, peak shift of a reproduced waveform occurs. Among  
methods known for compensating the peak shift is a write  
compensation method in which when recording a particular  
bit sequence of data, the phase of a signal representing  
a prescribed bit is adjusted.

20       A write compensation circuit portion which carries  
out the write compensation method has a delay generating  
section including a plurality of delay circuits having a  
plurality of buffers. The delay generating section  
25       controls the number of buffers which are driven by the delay  
circuits and generates a plurality of delay signals. The  
write compensation circuit portion has a selector which  
selects one of the plurality of delay signals to generate  
a write clock and generates write data in response to the  
30       write clock.

"A 300 Mb/s BiCMOS EPR4 Read Channel for Magnetic  
Hard Disks", pp. 378, 379, Proc. of IEEE, 1998, ISSCC,

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discloses a technique used for the delay generating section in the write compensation circuit portion, which utilizes VCO.

5           The delay amount of a clock can be held constant by means of the VCO technique in the delay circuit generating a write compensation amount. The stability of the delay amount can be protected from a source voltage change and variation in circuits caused by a temperature change and  
10           the like. When the VCO technique is applied to the delay generating section, additional circuits for compensating temperature and phase are required.

          A signal interpolation circuit has been developed  
15           which receives a pair of waveform signals having a phase difference, and generates a plurality of waveform signals spaced equally in phase between the pair of waveform signals. "A Portable Digital DLL Architecture for CMOS Interface  
20           Circuits", pp. 214-215, 1998, Symposium on VLSI Circuits Digest of Technical Papers discloses such a signal interpolation circuit. An example of the disclosed signal interpolation circuit is shown in Figure 23. A signal interpolation circuit 62e, for example, has two input  
25           terminals x1 and x2 and nine output terminals y1 through y9. When the signal interpolation circuit 62e receives signals Va and Vb having a different phase from each other from the input terminals X1 and X2, respectively, as shown in Figure 24A, the signal interpolation circuit 62e outputs a pair of output signals V<sub>k</sub>' and V<sub>s</sub>' having phases similar  
30           to those of the input signals Va and Vb, respectively, and seven interpolation signals V1' through Vr' spaced equally in phase between the pair of output signals V<sub>k</sub>' and V<sub>s</sub>' from the output terminals y1 through y9, respectively, as shown

in Figure 24B.

Figure 25 is a circuit diagram illustrating a specific configuration of the signal interpolation circuit 62a. The signal interpolation circuit 62a shown in Figure 25 includes a pair of inverters 41 and 42 and a first interpolation processor portion 10. The inverters 41 and 42 receive signals Va and Vb input from input terminals X1 and X2, respectively. The first interpolation processor portion 10 interpolates signals Va' and Vb' output from the inverters 41 and 42, respectively, and outputs a pair of output signals Vc and Ve having phases similar to those of the input signals Va' and Vb', respectively, and an interpolation signal Vd having a phase intermediate between the signals Vc and Ve.

The signals Vc through Ve output from the first interpolation processor portion 10 are input to three inverters 43, 44, and 45, respectively. The inverters 43, 44, and 45 output signals Vc' through Ve', respectively, to a second interpolation processor portion 20. The second interpolation processor portion 20 interpolates the signals Vc' through Ve' and outputs five signals Vf, Vg, Vh, Vi, and Vj. Specifically, the pair of signals Vc' and Vd' and the pair of signals Vd' and Ve' are subjected to interpolation similar to that in the first interpolation processor portion 10.

The signals Vf through Vj output from the second interpolation processor portion 20 are input to five inverters 46, 47, 48, 49, and 50, respectively. Output signals Vf' through Vj' of the inverters 46 through 50, respectively, are input to a third interpolation processor

portion 30. The third interpolation processor portion 30 interpolates the signals Vf' through Vj' and outputs nine signals Vk, Vl, Vm, Vn, Vo, Vp, Vq, Vr, and Vs. Specifically, the pair of signals Vf' and Vg', the pair of signals Vg' and Vh', the pair of signals Vh' and Vi', and the pair of signals Vi' and Vj' are subjected to interpolation similar to that in the first interpolation processor portion 10. The nine interpolating signals Vk through Vs output from third interpolation processor portion 30 are input to nine inverters 51 through 59, respectively. Outputs of the inverters 51 through 59 are output from output terminals y1 through y9 as output signals Vk' through Vs', respectively.

The first interpolation processor portion 10 includes a pair of first circuit blocks 11, a common second circuit block 12, and a pair of second circuit blocks 12. The pair of first circuit blocks 11 receive the outputs Va' and Vb' of the inverters 41 and 42, respectively. The common second circuit block 12 receives the outputs Va' and Vb' of the inverters 41 and 42, respectively. The pair of second circuit blocks 12 receive the outputs Va' and Vb' of the inverters 41 and 42, respectively.

Each first circuit block 11 has a similar configuration which includes a single inverter 11a as shown in Figure 26A. All the second circuit blocks 12 as well as the common second circuit block 12 have a similar configuration which includes a pair of inverters 12a as shown in Figure 26B. The common second circuit block 12 outputs a combination of outputs of the pair of inverters 12a.

As shown in Figure 27, the outputs Va' and Vb' of

the inverters 41 and 42, respectively, are input to the respective first circuit blocks 11, and are inverted to the output signals  $V_c$  and  $V_e$ . Outputs of the inverters 41 and 42 are input to the respective inverters 12a of the common second circuit block 12. A combination of the outputs of both the inverters 12a is the output  $V_d$  of the common second circuit block 12. The outputs  $V_c$  and  $V_e$  of the first circuit block 11

and the output  $V_d$  of the common second circuit block 12 are inverted by the inverters 43 and 45, and 44, respectively, to be output into the second interpolation processor portion 20.

In the second interpolation processor portion 20, the output signal  $V_c'$  of the inverter 43 and the output  $V_d'$  of the inverter 44 are input to the respective first circuit blocks 11 and a single common second circuit block 12. The outputs  $V_f$  and  $V_h$  are output from the respective first circuit blocks 11. The output  $V_g$  is output from the common second circuit block 12. The output signal  $V_d'$  of the inverter 44 and the output  $V_e'$  of the inverter 45 are input to the respective first circuit blocks 11 and a single common second circuit block 12. The outputs  $V_h$  and  $V_j$  are output from the respective first circuit blocks 11. The output  $V_i$  is output from the common second circuit block 12. The outputs  $V_f$  through  $V_j$  are input to the inverters 46 through 50. The inverters 46 through 50 output the signals  $V_f'$  through  $V_j'$ , respectively.

In the third interpolation processor portion 30, the output signals  $V_f'$  through  $V_j'$  from the inverters 46 through 50 are input to the respective first circuit blocks 11. An output signal of each pair of adjacent

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The inverters 11a and 12a in each signal interpolation circuit invert the level of an output signal when an input signal goes to a state which is higher than a predetermined threshold voltage  $V_{th}$  from a lower state, or when the input signal goes to the lower state from the higher state. As shown in Figure 28A, when the output  $V_d$  of the common second circuit block 12 is input to the inverter 44, the input signal  $V_d$  goes from the state which is higher than the threshold voltage  $V_{th}$  to the lower state and the level of the output signal of the inverter 44 is inverted. Therefore, the output signal  $V_d'$  of the inverter 44 ideally has a phase intermediate between those of the signals  $V_o'$  and  $V_e'$  output from the inverters 43 and 45 as shown in Figure 28B.

However, the threshold voltage  $V_{th}$  of the inverter is set in an appropriate voltage range. The output  $V_d$  of



the common second circuit block 12 has a state in which there is substantially no change in a voltage for an appropriate time as shown in Figure 28C. For this reason, the signal  $V_d'$  does not have an intermediate phase which does not space  
5 equally in phase between the signals  $V_c'$  and  $V_e'$  output from the inverters 43 and 45. A pair of signals having a phase difference is unlikely to be linearly interpolated.

#### SUMMARY OF THE INVENTION

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According to one aspect of the present invention, a write compensation circuit of a recording device includes a first delay portion driven by a first driving voltage, for receiving a clock signal, delaying the clock signal by  
15 a first delay time, and outputting the delayed clock signal; and a voltage supplying portion for supplying the first driving voltage to the first delay portion in such a manner that the first delay time is substantially equal to a clock period of the clock signal.

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In one embodiment of this invention, the voltage supplying portion includes a second delay portion driven by a second driving voltage and having the same configuration as that of the first delay portion, for receiving a clock  
25 signal, delaying the clock signal by a second delay time, and outputting the delayed clock signal; a determining portion for determining whether the second delay time is within a predetermined range; and a voltage select portion for selecting, according to a result of determination of  
30 the determining portion, the first driving voltage supplied to the first delay portion and selecting the second driving voltage supplied to the second delay portion.

In one embodiment of this invention, the first delay portion includes a selector for selecting a predetermined pattern in response to a select signal; and a delay circuit for delaying the clock signal by a delay amount corresponding to the predetermined pattern selected by the selector.

According to another aspect of the present invention, a signal interpolation circuit in which a pair of input signals having different phases are split into a pair of output signals having a phase similar to that of the pair of input signals, respectively, and an output signal having a phase intermediate between the phases of the pair of output signals; and by including a plurality of elements, the pair of output signals and the output signal having the intermediate phase have substantially the same propagation speed, further includes a control section for controlling the propagation speed.

In one embodiment of this invention, the control section controls propagation speeds of input and output signals into and from each of the plurality of elements.

In one embodiment of this invention, the control section controls speeds of input and output signals into and from each of the plurality of elements.

In one embodiment of this invention, the control section adjusts propagation speeds of input and output signals into and from each of the plurality of elements in accordance with the phase difference of the pair of input signals.

In one embodiment of this invention, the control

section adjusts propagation speeds of input and output signals into and from each of the plurality of elements in accordance with a change in the phase difference of the pair of input signals.

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Thus, the invention described herein makes possible the advantages of (1) providing a relative relationship between a delay of each buffer and a clock period by designing a delay circuit having a plurality of buffers in such a manner that an overall delay is substantially equal to the clock period; (2) providing a write compensation circuit which does not require circuit portions for providing temperature compensation and phase compensation in addition to a delay generating section and has a small-size circuit as compared with a write compensation circuit using VCO; and (3) providing a signal interpolation circuit capable of generating a high-accuracy interpolating signal which linearly interpolates a pair of signals having a phase difference.

These and other advantages of the present invention will become apparent to those skilled in the art upon reading and understanding the following detailed description with reference to the accompanying figures.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram illustrating an overall configuration of a magnetic recording and reproducing device 100 according to Example 1 of this invention.

Figure 2 is a block diagram illustrating a

5                Figure 3 is a block diagram illustrating a configuration of a preshift clock generating portion 7 included in the write compensation portion 3 shown in Figure 2.

15                Figure 4B is a block diagram illustrating another example of a configuration of the preshift clock determining portion 8 included in the preshift clock generating portion 7 shown in Figure 3.

20            Figure 5 is a circuit diagram illustrating an example of a configuration of a delay circuit 212, 13, or 14 shown in Figures 4A and 4B, or a delay circuit portion 19 shown in Figure 6.

25            Figure 6 is a block diagram illustrating an adaptive power source voltage generating portion 11 included in the preshift clock generating portion 7 shown in Figure 3.

Figure 7 is a timing chart representing a  
30 relationship between a clock signal 52 and pulse signals P1  
through P7.

Figure 8 is a block diagram illustrating a

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Figure 13B is a graph showing the inverted output signals shown in Figure 13A of the first and second circuit blocks included in the signal interpolation circuit of this

invention.

Figure 14A is a circuit diagram illustrating another example of a concrete configuration of a first circuit block used in the signal interpolation circuit of this invention.

Figure 14B is a circuit diagram illustrating another example of a concrete configuration of a second circuit block used in the signal interpolation circuit of this invention.

Figure 15A is a circuit diagram illustrating an example of an inverter used in the first and second circuit blocks shown in Figure 14.

Figure 15B is a circuit diagram illustrating another example of an inverter used in the first and second circuit blocks shown in Figure 14.

Figure 16 is a circuit diagram illustrating a concrete configuration of the signal interpolation circuit of this invention using the first and second circuit blocks shown in Figure 14.

Figure 17A is a graph showing an example set of output signals of the first and second circuit blocks shown in Figure 12 included in the signal interpolation circuit of this invention.

Figure 17B is a graph showing the inverted output signals shown in Figure 17A of the first and second circuit blocks included in the signal interpolation circuit of this

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Figure 22 is a diagram illustrating a configuration of a signal interpolation portion used in the preshift clock determining portion shown in Figure 21.

5                Figure 24A is a graph illustrating an input signal  
of the signal interpolation circuit portion shown in  
Figure 23.

Figure 24B is a graph illustrating an output signal  
10 of the signal interpolation circuit portion shown in  
Figure 23.

Figure 25 is a circuit diagram illustrating a concrete configuration of the signal interpolation circuit portion shown in Figure 23.

Figure 26A is a circuit diagram illustrating a concrete configuration of a first circuit block shown in Figure 25.

Figure 26B is a circuit diagram illustrating a concrete configuration of a second circuit block shown in Figure 25.

25            Figure 27 is a circuit diagram illustrating a concrete configuration of a signal interpolation circuit included in the signal interpolation circuit portion shown in Figure 25.

30            Figure 28A is a graph showing an ideal set of output  
signals of the first and second circuit blocks included in  
the signal interpolation circuit shown in Figure 27.



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30                Figure 2 illustrates a configuration of the write  
compensation portion 3 included in the magnetic recording  
and reproducing device 100 shown in Figure 1. As shown in  
Figure 2, the write compensation portion 3 includes a

Figure 3 illustrates a configuration of the preshift clock generating portion 7 included in the write compensation portion 3. As shown in Figure 3, the preshift clock portion 7 includes a preshift clock determining portion 8 (first delaying portion) and an adaptive power source voltage generating portion 11 (voltage supplying portion). In Figure 3, the preshift clock generating portion 7 receives the clock signal 52 and patterns 62, 63, and 64, and outputs a write clock 55. The clock signal 52, and the patterns 62, 63, and 64 are input via the signal line 106, and signal lines 114, 115, and 116, respectively, into the preshift clock generating portion 7. The patterns 62, 63, and 64 are constant patterns which are generated by a pattern generating portion (not shown) included in the magnetic recording and reproducing device 100.

The adaptive power source voltage generating portion 11 generates a driving voltage VDD which causes an

overall delay amount of a delay circuit portion (described later) to be substantially equal to the clock signal 52. The preshift clock determining portion 8 generates the write clock signal 55 based on the received clock signal 52, the patterns 62, 63, and 64, the driving voltage VDD, and the select signal 53.

Figure 4A illustrates an example of a configuration of the preshift clock determining portion 8 included in the preshift clock generating portion 7. The preshift clock determining portion 8 includes a delay circuit 12 and a selector 15.

The delay circuit 12 delays the clock signal 52 received via the signal line 106 by a delay amount corresponding to an input pattern from the selector 15, and outputs the delayed clock signal 52 as the write clock signal 55. The delay circuit 12 is driven by the driving voltage VDD generated by the adaptive power voltage portion 11 shown in Figure 3. For this reason, the greater the driving voltage VDD, the smaller the delay amount. In other words, the smaller the driving voltage VDD, the greater the delay amount.

The selector 15 selects and outputs one of the patterns 62, 63, and 64 which are input to the selector 15 via the signal lines 114, 115, and 116, respectively. The selected pattern is input via a signal line 117 from the selector 15 to the delay circuit 12. The pattern selection by the selector 15 is carried out in response to the select signal 53 which is input via the signal line 109 to the selector 15.

Figure 4B illustrates another example of a configuration of the preshift clock determining portion 8 included in the preshift clock generating portion 7 shown in Figure 3. The preshift clock determining portion 8A shown in Figure 4B includes delay circuits 212, 13, and 14, and a selector 15.

In Figure 4B, as is different from Figure 4A, each of the delay circuits 212, 13, and 14 has almost a constant delay amount, since the delay circuits 212, 13, and 14 receive constant patterns 62, 63, and 64, respectively. The delay circuits 212, 13, and 14 is driven by a driving voltage VDD as is the delay circuit 14 in Figure 4A. Therefore, the delay amounts vary depending on the magnitude of the driving voltage VDD.

A clock signal 52 input to the preshift clock 8A is delayed by predetermined delay amounts by the delay circuits 212, 13, and 14. The delayed clock signals are output via signal lines 111, 112, and 113 into the selector 15. The selector 15 also receives a clock signal 52, which is not delayed, other than the delayed clock signals. The selector 15 selects one of the three delayed clock signals and the clock signal 52 in response to a select signal 53 received via a signal line 109. The selector 15 outputs the selected clock signal into a write clock 55 via a signal line 108.

Figure 5 illustrates an example of a configuration of the delay circuits 212 shown in Figures 4A and 4B. The delay circuits 13 and 14 have the same configuration as that of the delay circuit 12.

Here the signal lines 106 at the input sides of the delay circuits 212, 13, and 14 in Figures 4A and 4B correspond to a signal line 12-i in Figure 5. The signal line 108 at the output side of the delay circuit 12 in Figure 4A and the signal lines 111, 112, and 113 at the output sides of the delay circuits 212, 13, and 14 in Figure 4B correspond to a signal line 12-o in Figure 5. The signal line 117 via which the delay circuit 12 receives a signal pattern in Figure 4A and the signal lines 114, 115, and 116 via which the delay circuits 212, 13, and 14 receive the signal patterns 62, 63, and 64 in Figure 4B correspond to a signal line 12-p in Figure 5.

The delay circuit 12 in Figure 5 includes m buffer circuits 12b-1 through 12b-m and m switching circuits 12s-1 through 12s-m.

The delay amount of a signal in the delay circuit 12 in Figure 5 is determined when only one of the switching circuits 12s-1 through 12s-m is in the ON state and the others are in the OFF state. When one of the switching circuits 12s-1 through 12s-m is in the ON state, a signal input from the signal line 12-i is delayed by the buffer circuit 12b-1 through 12b-m to a buffer circuit corresponding to the ON-state switching circuit, and output from the signal line 12-o. For example, when the switching circuit 12s-3 is in the ON state, a signal input from the signal line 12-i is delayed by the buffer circuits 12b-1 to 12b-3, and output from the signal line 12-o.

The ON/OFF switching of the switching circuits 12s-1 through 12s-m is controlled by patterns input via a signal line 12-p. The delay amounts of the delay

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signal P4 obtained by inverting the pulse signal P3. The OR circuit 40 calculates the logical OR of the pulse signals P4 and P6 output from the delay amount determining circuit 17 and outputs a pulse signal P7.

5                   The voltage select circuit 16 receives the determination signal P3 and the pulse signals P5 and P7 via the signal lines 123, 125, and 127. The voltage select circuit 16 outputs the target driving voltages VDD and VDD'.  
10       As described above, the driving voltage VDD drives the delay circuits 212, 13, and 14 shown in Figures 4A and 4B. The driving voltage VDD' drives the delay circuit portion 19. The voltage select circuit 16 selects one of a plurality of predetermined different voltages in accordance with the determination signal P3 and the pulse signal P5 and outputs  
15       the selected voltage as the driving voltage VDD'. The voltage select circuit 16 selects one of a plurality of predetermined different voltages in accordance with the determination signal P3 and the pulse signal P7 and outputs  
20       the selected voltage as the driving voltage VDD.

25       The determination signal P3 is used for indicating whether of the plurality of voltages a higher voltage or lower voltage should be output. Specifically, when the determination signal P3 has a LOW level, the signal P3 indicates that a lower voltage of the plurality of voltages is output. When the determination signal P3 has a HIGH level, the signal P3 indicates that a higher voltage of the plurality of voltages is output.

30                   The delay circuit portion 19 has a configuration similar to those of the delay circuits 212, 13, and 14 in Figures 3 and 4A. As is different from the delay



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marked with the left-side circle C1, the delay amount of the pulse signal P2 relative to the pulse signal P1 is greater than the target delay amount. This causes the determination signal P3 to go to the HIGH level. At the time point marked with the right-side circle C2, the delay amount of the pulse signal P2 relative to the pulse signal P1 is smaller than the target delay amount. This causes the determination signal P3 to go to the LOW level. As described above, the pulse signal P4 is a NOT of the determination signal P3 and thus has an inverted waveform of the determination signal P3.

The pulse signal P7 is obtained by a logical OR operation of the pulse signals P4 and P6. As shown in Figure 7, the pulse signal P7 is output in response to the pulse signal P6 only for a period during which the pulse signal P4 has the LOW level. As described above, the period during which the pulse signal P4 has the LOW level (the determination signal P3 has the HIGH level) corresponds to a period during which the driving voltage VDD' rises. The timing of update of the driving voltage VDD is actually controlled using the pulse signal P7 generated based on the pulse signal P6. The update of the driving voltage VDD is carried out in the period during which the driving voltage VDD' rises.

Figure 8 illustrates a configuration of the voltage select circuit 16 included in the adaptive power source voltage generating portion 11 shown in Figure 6. The voltage select circuit 16 includes a resistor 30, switching circuits 31 and 33, and a bidirectional control shift circuit 32.

The bidirectional control shift circuit 32 includes D flip-flops 32f-1 through 32f-9, two-input-and- one-output multiplexers 32m-1 through 32m-5, and OR circuits 32o-1 and 32o-2.

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Each of the D flip-flops 32f-1 through 32f-5 receives data from a D flip-flop at the front or rear stage in synchronization with the rising edge of the pulse signal P5 obtained via the signal line 125. Each of the multiplexers 32m-1 through 32m-5 selects data to be stored in the corresponding D flip-flop in accordance with the level of the pulse signal P3. The OR circuit 32o-1 outputs a logical OR of control signals S4 and S5. The OR circuit 32o-2 outputs a logical OR of control signals S1 and S2.

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Any but only one of the D flip-flops 32f-1 through 32f-5 holds data having a value "1". The remaining D flip-flops hold data having a value "0". When the determination signal P3 has the LOW level (the delay amount of the pulse signal P2 is smaller than the target delay amount), a D flip-flop holding the value "1" flip-flops another D flip-flop at the front stage (downward in Figure 8). When the determination signal P3 has the HIGH level (the delay amount of the pulse signal P2 is greater than the target delay amount), a D flip-flop holding the value "1" flip-flops another D flip-flop at the rear stage (upward in Figure 8). The values held by the D flip-flops 32f-1 through 32f-5 are input to the D flip-flops 32f-6 through 32f-9 and the switching circuit 31 as the control signals S1 through S5, respectively.

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On the other hand, each of the D flip-flops 32f-

6 through 32f-9 receives data held by the D flip-flops 32f-1 through 32f-4, respectively, in synchronization with the rising edge of the pulse signal P7 obtained via the signal line 127. Any but only one of the D flip-flops 32f-6 through 32f-9 holds data having the value "1". The remaining D flip-flops hold data having the value "0". The values held by the D flip-flops 32f-6 through 32f-9 are input to the switching circuit 33 as the control signals S6 through S9, respectively.

With the above-described configuration, the bidirectional control shift circuit 32 causes any but only one of the control signals S1 through S5 to go to the HIGH level, leaving the remaining control signals at the LOW level. The bidirectional control shift circuit 32 causes any but only one of the control signals S6 through S9 to go to the HIGH level, leaving the remaining control signals at the LOW level.

In Figure 8, one end of the resistor 30 is connected to a power source voltage VCC while the other end of the resistor 30 is connected to a ground voltage. By means of resistance division, voltages at points R1 through R5 are supplied as voltages V1 through V5 to the switching circuit 31. Voltages V1 through V4 at points R1 through R4 are supplied to the switching circuit 33. Here  $V1 > V2 > V3 > V4 > V5$  is satisfied.

The switching circuit 31 includes a plurality of switching elements 31-1 through 31-5. An end of each switching elements 31-1 through 31-5 is supplied with the corresponding voltages V1 through V5. The control signals S1 through S5 are used for controlling ON/OFF

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**Data stored in the D flip-flops 32F-6 through 32F-9**

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A relationship between the input pulse signal P1 and the output pulse signal P2 is classified into two cases. One case is that the output pulse signal P2 has the LOW level at the rising edge of the input pulse signal P1 (circle C2 at the right side of Figure 7). The other case is that the output pulse signal P2 has the HIGH level at the rising edge of the input pulse P1 (circle C1 at the right side of Figure 7).

When the output pulse signal P2 has the LOW level at the rising edge of the input pulse signal P1, the delay amount (actual delay amount) of the output pulse signal P2 relative to the input pulse signal P1 is smaller than the target delay amount, the pulse width of the input pulse signal P1 corresponds to the target delay amount.

The output pulse signal P2 has the LOW level at the rising edge of the input pulse signal P1, the delay amount determination circuit 17 outputs the determination signal P3 having the LOW level. This is because that the flip-flop 36 of the delay amount determination circuit 17 receives the level (LOW level) of the output pulse signal P2 as data at the rising edge of the input pulse signal P1. As described above, the voltage select circuit 16 lowers the driving voltage VDD' below the current voltage in response to the determination signal P3 having the LOW level. As a result, the delay amount of the output pulse signal P2 relative to the input pulse signal P1 is increased. As described above, the delay amount of the output pulse signal P2 relative to the input pulse signal P1 becomes closer to the target delay amount.

The output pulse signal P2 has the HIGH level at the

rising edge of the input pulse signal P1, the delay amount determination circuit 17 outputs the determination signal P3 having the HIGH level. This is because that the flip-flop 36 of the delay amount determination circuit 17 receives the level (HIGH level) of the output pulse signal P2 as data at the rising edge of the input pulse signal P1. As described above, the voltage select circuit 16 raises the driving voltage VDD' above the current voltage in response to the determination signal P3 having the LOW level. As a result, the delay amount of the output pulse signal P2 relative to the input pulse signal P1 is decreased. As described above, the delay amount of the output pulse signal P2 relative to the input pulse signal P1 becomes closer to the target delay amount.

As a result of the feedback, the value of the driving voltage VDD' is controlled in such a manner that the delay amount of the output pulse signal P2 relative to the input pulse signal P1 becomes substantially equal to the target delay amount. The value of the driving voltage VDD is updated when the driving voltage VDD' rises. Therefore, the delay amounts of the delay circuits 212, 13, and 14 driven by the driving voltage VDD can have a linear relationship with the clock period.

(Example 2)

A signal interpolation circuit portion 162e of this invention shown in Figure 10 includes signal interpolation circuits. Each interpolation circuit includes a first circuit block 11A and a second circuit block 12A. As shown in Figure 11A, the first circuit block 11A includes an inverter 11a and a resistor 11b arranged in series. As shown in Figure 11B, the second circuit block 12A includes



a pair of inverters 12a and a pair of resistors 12b connected in series to the pair of inverters 12a, respectively. The resistors 12b are combined to provide a single output terminal. The other parts of the configuration are similar to those of the signal interpolation circuit 25.

Figure 12 illustrates a configuration of a main part of a first interpolation processor portion 10A in the signal interpolation circuit of this invention. Output signals Va' and Vb' having different phases output from the inverters 41 and 42, respectively, are input to the respective first circuit blocks 11A. The first circuit blocks 11A outputs the respective signals Vc and Ve using the inverter 11a and the resistor 11b arranged in series. The outputs of the inverters 41 and 42 are input to the respective inverters 12a of a common second circuit block 12A. The outputs of the inverters 41 and 42 pass through the inverters 12a and the resistors 12b connected in series to the respective inverters 12a, and are combined to be output as a signal Vd. The outputs Vc and Ve of the first circuit block 11A and the output Vd of the common second circuit block 12A are input to the inverters 43 and 45 and the inverter 44, respectively, and output as output signals Vc', Ve', and Vd', respectively.

Here the resistances of the resistors 12b of the common second circuit block 12A are represented by R1 and R3. The resistance of the resistor 11b of the first circuit block 11A is represented by R2. These resistors have a relationship represented by the following expression.

$$R2 = (R1 + R3) / 2 \quad \dots \text{expression (1)}$$

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	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100	2101	2102	2103	2104	2105	2106	2107	2108	2109	2110	2111	2112	2113	2114	2115	2116	2117	2118	2119	2120	2121	2122	2123	2124	2125	2126	2127	2128	2129	2130	2131	2132	2133	2134	2135	2136	2137	2138	2139	2140	2141	2142	2143	2144	2145	2146	2147	2148	2149	2150	2151	2152	2153	2154	2155	2156	2157	2158	2159	2160	2161	2162	2163	2164	2165	2166	2167	2168	2169	2170	2171	2172	2173	2174	2175	2176	2177	2178	2179	2180	2181	2182	2183	2184	2185	2186	2187	2188	2189	2190	2191	2192	2193	2194	2195	2196	2197	2198	2199	2200	2201	2202	2203	2204	2205	2206	2207	2208	2209	2210	2211	2212	2213	2214	2215	2216	2217	2218	2219	2220	2221	2222	2223	2224	2225	2226	2227	2228	2229	2230	2231	2232	2233	2234	2235	2236	2237	2238	2239	2240	2241	2242	2243	2244	2245	2246	2247	2248	2249	2250	2251	2252	2253	2254	2255	2256	2257	2258	2259	2260	2261	2262	2263	2264	2265	2266	2267	2268	2269	2270	2271	2272	2273	2274	2275	2276	2277	2278	2279	2280	2281	2282	2283	2284	2285	2286	2287	2288	2289	2290	2291	2292	2293	2294	2295	2296	2297	2298	2299	2300	2301	2302	2303	2304	2305	2306	2307	2308	2309	2310	2311	2312	2313	2314	2315	2316	2317	2318	2319	2320	2321	2322	2323	2324	2325	2326	2327	2328	2329	2330	2331	2332	2333	2334	2335	2336	2337	2338	2339	2340	2341	2342	2343	2344	2345	2346	2347	2348	2349	2350	2351	2352	2353	2354	2355	2356	2357	2358	2359	2360	2361	2362	2363	2364	2365	2366	2367	2368	2369	2370	2371	2372	2373	2374	2375	2376	2377	2378	2379	2380	2381	2382	2383	2384	2385	2386	2387	2388	2389	2390	2391	2392	2393	2394	2395	2396	2397	2398	2399	2400	2401	2402	2403	2404	2405	2406	2407	2408	2409	2410	2411	2412	2413	2414	2415	2416	2417	2418	2419	2420	2421	2422	2
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The control current flowing through the inverter portion 25 is changed depending on the applied bias voltage VB. As the bias voltage VB becomes greater, the control current flowing through the inverter portion 25 is increased. As the bias voltage VB becomes smaller, the control current flowing through the inverter portion 25 is decreased.

Figure 15B illustrates another example of the inverters 11a' and 12a' to which the bias voltage is applied. In this inverter 11a' (or 12a'), the drain of a first MOSFET 21 to which the bias voltage is applied is connected to the drain of a second MOSFET 22. The drain of a fourth MOSFET 24 which is common to the gate of the first MOSFET 21 is connected to the inverter portion 25. The drain of a third MOSFET 23 is connected to the inverter portion 25. The gate of the third MOSFET 23 and the gate of the second MOSFET 22 are connected to each other. The gate and drain of the second MOSFET 22 are connected to each other.

Also in the inverter 11a' (or 12a'), the dimension ratio of the first MOSFET 21 and the fourth MOSFET 24 and the dimension ratio of the second MOSFET 22 and the third MOSFET 23 each are 1:n. When the bias voltage VB is applied to the first MOSFET 21, a current I flows from the second MOSFET 22 to the first MOSFET 21. Meanwhile, a control current nI which is n times as large as the current I flows from the third MOSFET 23 to the fourth MOSFET 24. The current nI adjusts the operating speed of the inverter portion 25.

The control current flowing through the inverter 25 is changed depending on the applied bias voltage VB. As the

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receives the output of the first circuit block 11B can be decreased. The product of the resistance of resistor 12b and the input load capacitance of the inverter 44 which receives the output of the second circuit block 12B also  
5 can be decreased. For this reason, the signal  $V_d$  output from the second circuit block 12B has a larger change in voltage relative to time than the case shown in Figure 17A. Signals  $V_o'$ ,  $V_d'$ , and  $V_e'$  output from the inverters 43, 44, and 45, respectively, thus have a smaller phase difference  
10 as shown in Figure 17D.

As described above, an interpolation signal can be obtained in accordance with a phase difference between input signals. As shown in Figure 10, the interpolation  
15 processor portions 10A, 20A, and 30A can perform appropriate interpolation in accordance with phase differences between input signals, even when a phase difference between signals input to the first interpolation processor portion 10A is different from a phase difference between signals input to the second interpolation processor portion 20A, and a phase  
20 difference between signals input to the second interpolation processor portion 20A is different from a phase difference between signals input to the third interpolation processor portion 30A.

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(Example 3)

The inverters 11a provided in the respective first circuit block 11A and the inverters 12a provided in the respective second circuit block 12A may be supplied with  
30 the respective bias voltages which are changed in accordance with input signals having arbitrary phase difference. Figure 18 is a block diagram illustrating an example of a compensation circuit used in this case. A compensation

circuit 60 includes a flip-flop 61 (hereinafter referred to as FF) and a preshift clock generating portion 62. The FF 61 receives a data signal 71. The preshift clock generating portion 62 receives a clock signal 72 and a select signal 73. The preshift clock generating portion 62 outputs a write clock 75 based on the clock signal 72 and the select signal 73. The output write clock 75 is input to FF 61. FF 61 outputs write data 74 based on the data signal 71 in synchronization with the output write clock 75.

Figure 19 is a block diagram illustrating an internal configuration of the preshift clock generating portion 62. The preshift clock generating portion 62 includes a preshift clock determining portion 62a and an adaptive power source voltage generating portion 62b. The clock signal 72 is input to both the preshift clock determining portion 62a and the adaptive power source voltage generating portion 62b. The adaptive power source voltage generating portion 62b outputs a driving voltage VDD to the preshift clock determining portion 62a in response to the received clock signal 72. The preshift clock determining portion 62a is driven by the driving voltage VDD.

The preshift clock determining portion 62a receives the select signal 73 directly. The preshift clock determining portion 62a driven by the driving voltage VDD outputs the write clock 75 based on the clock signal 72 and the select signal 73.

Figure 20 is a block diagram illustrating an internal configuration of the preshift clock determining portion 62a. The preshift clock determining portion 62a

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The driving voltage VDD supplied to the delay

[illegible]



circuit portion 62d is designed to hold an overall delay amount of delayed clocks output from the buffers 63 equal to a clock period. For this reason, the delay amount of a delayed clock output each buffer 63 is equal to  $1/n$  of the clock period. The driving voltage VDD supplied to each buffer 63 is determined by the adaptive power source voltage generating portion 62b in response to the clock signal 72 input to the the adaptive power source voltage generating portion 62b.

Note that in Figure 20, one line represents signal lines for the delayed clocks 1 through n output from the delay circuit portion 62d.

Figure 22 is a block diagram illustrating an internal configuration of the signal interpolation portion 62c. The signal interpolation portion 62c includes n signal interpolation circuit portions 162a which have a configuration similar to that of the signal interpolation circuit portion 162a shown in Figure 10. First and second circuit blocks 11B and 12B in each signal interpolation circuit portion 162a shown in Figure 22 includes the inverters 11a' and 12a' shown in Figures 14A and 14B, respectively. As shown in Figures 14A and 14B, the resistors 11b and 12b are connected to the inverters 11a' and 12a', respectively.

In each signal interpolation circuit portion 162a, the driving voltage VDD generated by the adaptive power source voltage generating portion 62b (Figure 19) is supplied to the inverters 11a' and 12a' in the first and second circuit blocks 11B and 12B, respectively, as a bias voltage for control thereof. Each signal interpolation

circuit portion 162a receives a pair of delayed clocks successively output from the delay circuit portion 62d (Figure 21). The delayed clocks 1 and 2 are input to a signal interpolation circuit portion 162a. The delayed  
5 clocks 2 and 3 are input to another signal interpolation circuit portion 162a. Similarly, the delayed clocks (n-1) and n are input to a signal interpolation circuit portion 162a.

10 Each signal interpolation circuit portion 162e receives a pair of input signals having a phase difference and outputs a pair of output signals having a phase similar to that of the corresponding input signal. Each signal  
15 interpolation circuit portion 162e also outputs seven output signals interpolating between the phases of the pair of output signals. As a result, when the delay circuit portion 62d outputs delayed clocks based on the clock  
20 signal 72 input to each signal interpolation portion 62c (Figure 20), each delayed clock is output from each signal interpolation circuit portion 162e as interpolating signals having an increased level of delay resolution.

Note that in Figure 20, one line represents signal  
25 lines for the interpolating signals output from the signal interpolation circuit portions 62c.

In each signal interpolation circuit portion 162e,  
the driving voltage VDD is used as a bias voltage VB for  
the inverters 11a' and 11b'. In the adaptive power source  
30 generating portion 62b in Figure 19, the driving  
voltage VDD is set to a high level when the clock signal 72 has a short period. The driving voltage VDD is set to a low level when the clock signal 72 has a long period. For this

reason, the overall delay amount in the delay circuit portion 62 shown in Figure 20 becomes equal to the period of the clock signal 72.

5                   Therefore, when the clock signal 72 has a short period, a pair of input signals (delayed clock) input to the signal interpolation circuit portion 162e shown in Figure 22 has a small phase difference. When the clock signal 72 has a long period, a pair of input signals (delayed clock) input to the signal interpolation circuit portion 162e has a large phase difference. For this reason, when a pair of input signals input to the signal interpolation circuit portion 162e has a large phase difference, the driving voltage VDD is decreased. When a pair of input signals input to the signal interpolation circuit portion 162e has a small phase difference, the driving voltage VDD is increased. As a result, when a pair of input signals input to the signal interpolation circuit portion 162e has a small phase difference, the amount of a control current flowing through an inverter 11a' or 12a' in the signal interpolation circuit portion 162e is relatively larger as compared with when the phase difference of the pair of input signals is large. The signal interpolation circuit portion 162e thus can perform signal interpolation in accordance with the period of the clock signal 72.

                  According to this invention, the delay circuit having a plurality of buffers is designed to constantly have an overall delay amount equal to a clock period. The delay amount for each buffer can have a linear relationship with the clock period. For this reason, the delay amount of a signal in the delay circuit of the write compensation circuit

[illegible]

The signal interpolation circuit of this invention includes a control section for controlling the propagation speed of a signal as described above. This control section generates interpolating signals, which interpolate a pair of signals having a phase difference, with high accuracy. Further, since the propagating speed of a signal is controlled in accordance with an arbitrary phase difference of the input signals, the signal interpolation circuit of this invention is suitable for a write compensation circuit for writing data onto a storage device.

Various other modifications will be apparent to and can be readily made by those skilled in the art without departing from the scope and spirit of this invention. Accordingly, it is not intended that the scope of the claims appended hereto be limited to the description as set forth herein, but rather that the claims be broadly construed.